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Strategic Design of Engineering Education for the Flat World*

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We believe that two critical success factors for an engineer in the flat world are an ability to adapt to changes and to be able to work at the interface of different disciplines. Instead of educating traditional domain-specific and analysis-orientated engineers, we believe that the focus should be on educating and graduating strategic engineers who can realize complex systems for changing markets in a collaborative, globally distributed environment. We identify three key drivers that we believe are foundational to future engineering design education programs. These drivers are a) emphasis on strategic engineering, b) mass customization of courses, c) utilization of IT-enabled environments for distributed education. Strategic engineering is a field that relates to the design and creation of complex systems that are adaptable to changes. Mass customization of courses refers to adapting the course material to educational goals and learning styles of different students. IT enabled environments bring distributed students and instructors closer in the form of a virtual classroom.

Keywords: strategic engineers; mass customization of education; distributed education; flat world; product creation

MOTIVATION AND BACKGROUND

IN HIS RECENT BOOK, *The World is Flat* [1], Thomas L. Friedman showcases Georgia Tech's approach to education in the 21st century. 'What the Georgia Tech model recognizes is that the world is increasingly going to be operating off the flat-world platform, with its tools for all kinds of horizontal collaboration', writes Friedman. In the chapter *The Right Stuff*, Friedman describes how Georgia Tech has worked over the last 10 years to attract and retain more students with more wide-ranging interests, with the thought that these students are more flexible and able to adapt and work across disciplines. According to Friedman, 'Georgia Tech is producing not just more engineers, but the right kind of engineers'. These future engineers will be intellectual leaders prepared for success in an era that demands flexibility, creativity, experimentation and teamwork across traditional boundaries.

The strategic goal number one of Georgia Tech's College of Engineering (COE) is to 'develop rigorous, innovative, experiential educational programs that integrate disciplines and that engage students in the excitement of learning, motivate their passion for positive societal impact and develop leaders for the future'. Being an academic unit of the COE, Georgia Tech Savannah, according to its mission statement, 'seeks to be a technology-enabled academic enterprise of diverse students, faculty and staff that is globally recognized for

innovation in engineering-centric education, scholarship and economic development'.

In a recent interview, Don Giddens, Dean of the College of Engineering at Georgia Tech, articulated his view on engineering in a rapidly changing world [18]. Among others, he posed the following statements, which resonate with what is presented in the reminder of this paper:

- . . . however, there will be other dimensions to engineering—creating, dealing with very complex systems, . . . —GTS response: Complex Engineered Systems.
- The ability to look at systems is going to be important.
- To characterize everything as a competition is not the best way to look at it. We want to educate engineers who are collaborative, but who are at the very top—who are leaders of international teams . . . —GTS response: Product Creation Network.
- Not only do we want to educate engineers at Georgia Tech to solve problems, but we really want to educate engineers who are able to help society pose problems and issues that are important.—GTS response: Strategic Engineers.
- One thing that technology can do is help disperse wealth—through the transfer of goods and services and the transfer of information. Technology can have a significant role in a distribution of wealth to prevent a polarization in wealth.—GTS response: Service Education.

The Woodruff School Savannah's response to globalization is: 'innovation has no boundaries'. In

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order to comprehend this, one needs to be in harmony with a particular mindset regarding engineering innovation. Quoting George Bernard Shaw (*Back to Methuselah*, 1921), 'You see things; and you say, "Why?"'. But I dream things that never were; and say "Why not?"', we always articulate the following innovation-enabling question: 'Tell me why things cannot be done?' In addition to this, we strive to live up to what Wayne Gretsky once answered to the question about the secret behind his success as a hockey player: 'I skate to where the puck is going to be, not where it has been'.

In order to respond to globalization and produce the right kind of engineers for the flat world, our focus at the Woodruff School of Mechanical Engineering in Savannah is on developing strategic engineers. These are engineers who know how to realize complex engineered systems for changing markets in collaborative, globally distributed environments thereby safeguarding the economic viability of the companies they represent and hence fostering the prosperity of our country [2]. Such strategic engineers are also:

- Great collaborators, i.e. engineers who can build global supply chains.
- Great leveragers, i.e. engineers who can leverage technology so that one person can do the job of twenty.
- Great synthesizers, i.e. engineers who can take 'A' and 'B' to make 'C'.
- Great localizers, i.e. engineers who can create a small business locally.
- Great adaptors, i.e. engineers who can adapt to rapid and large changes.

However, in order to educate strategic engineers with the capabilities outlined above, engineering education has to undergo radical change to accommodate and finally meet the requirements emerging from continuously progressing globalization. At the Woodruff School Savannah, and in consultation with our Product Creation Network (PCN) partners from the United States, Europe and India, three key drivers have been identified to form the basis of a strategy for design engineering education programmes tailored for the flat world. These are:

- From a technical point of view, an emphasis on strategic engineering.
- From an educational perspective, the realization of mass customization of courses.
- From a technology-centric perspective, the development of IT-enabled environments for globally distributed education without any boundaries whatsoever.

EDUCATION OF STRATEGIC ENGINEERS FOR THE NEAR TOMORROW

In 2004, the National Academy of Engineering published a report summarizing visions of what the

engineering profession might be like in the year 2020 [3]. They had deployed so-called scenario-based strategic planning to develop their prediction of the future. A year later, they published a follow-up report on how to educate the engineer of 2020 [4]. In brief, they made clear that engineering education has to be adapted to the challenges of the future, particularly with regard to globalization. In order to realize a new form of globally distributed engineering education which envisages:

- getting rid of any boundaries;
- new educational models encompassing the design of programmes and courses;
- novel ways to deliver programmes and courses;
- new IT-infrastructures;
- solutions for a number of other issues including accreditation, credit transfer, etc. which have to be developed.

In light of this, the term 'strategic engineering' can be understood in two ways. First, it signifies the development of strategies for realizing engineering education as required in the year 2020 settings. Second, it implies the development of new strategic role models, paving the way for a new kind of engineer, capable of encompassing various scientific fields. These engineers will be characterized by their competencies, which relate to knowledge, skills and attitude. Through their competencies they will be empowered to become capable of tackling the complicated multidisciplinary questions our society is facing.

In response to the COE's strategic goal number one, the Woodruff School of Mechanical engineering at Savannah seeks to develop rigorous, innovative, experiential educational programmes that integrate disciplines and engage students in the excitement of learning, motivate their passion for positive societal impact and develop leaders for the future.

Strategic engineering education seeks to foster design as the basis for adding value to the economy. In other words, design transforms technology, i.e. intellectual capital into economy (wealth). This transformation is shown in Fig. 1. In addition, design integrates engineering, market opportunities and customer demands, and it also facilitates the integration of academia and industry.

The central role of design in an engineering curriculum is increasingly recognized at various universities [5, 6]. We believe that design is at the core of engineering. Consequently, other important elements of a strategic engineering design programme have to be technology, business processes and users (Fig. 2). Integration of these elements into a design-centric curriculum requires reconceptualization of the current educational paradigm. Hence, scholarship in engineering education is an integral component of the strategic engineering design programme.

Some typical examples of applications that allow innovation at the interface between disciplinary

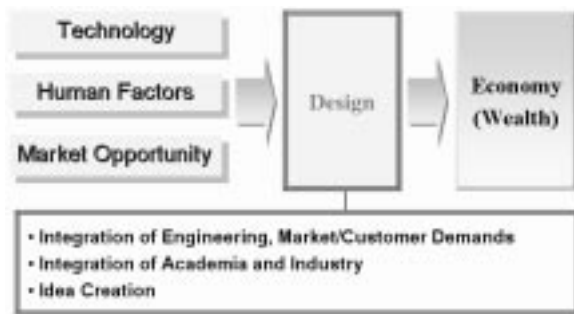


Fig. 1. Design as a means to creating value for the economy.

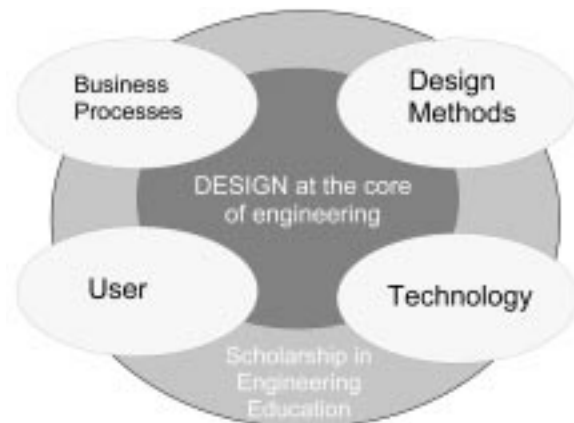


Fig. 2. Core elements of a strategic engineering design programme.

emphasis (e.g., fluid mechanics, materials, heat transfer and manufacturing) and system realization (e.g., design, manufacturing, life-cycle activities) in distributed engineering environments include:

- Design methods for complex engineered systems—product families and architectures, the design and analysis of knowledge and information flows.
- Example research: investigations that result in simulation-based, distributed engineering of complex engineered systems.
- Design, analysis, and fabrication aspects of products that employ ambient intelligence (are context aware, adaptive and anticipatory); embedded sensors, sensor networks that facilitate automated reconfiguration.
- Rapidly reconfigurable business processes including supply and value chains and e-commerce.
- Example research: investigations that are embodied in network/graph theory and that result in reconfigurable, dynamic chains.
- User observation methods and customer needs analysis relevant to product creation, development and testing.
- Example research: investigations that lead to symbiotic collaboration between humans through technology.
- Affective engineering techniques to design more satisfying products.

MASS CUSTOMIZATION OF COURSES

Engineering courses are currently mainly focused on the aspects of analysis. In addition to the analysis skills, a strategic engineer must possess critical thinking skills, abstraction and synthesis skills. Critical thinking allows them to observe a situation and frame the problem; abstraction skills are required to identify the crux of the problem, whereas synthesizing skills are important for utilizing available information to solve the problem.

To facilitate learning of these skills, a paradigm shift is required in the manner in which engineering courses are taught. Williams and Mistree [7] present a model for teaching engineering design courses, which relies on mass customization of courses relating to students' interests and learning styles. In other words, the emphasis is on offering a course to the individual in a group setting. Mass customization of courses is also important because in a multi-disciplinary design environment, individuals with different background knowledge, professional experience and preferred learning styles participate in the creation of new engineering systems [8].

The mass customization model of a course relies on creating an environment for active learning rather than passive one-way flow of information. The professor acts as an 'orchestrator' who architects the course content, motivates the students and provides the necessary scaffolding to facilitate learning. The orchestrator uses various tools to customize the course content for different individuals through various modes for managing student variety. These modes include tailoring of lectures, presentation style, examples, in-class offered at Georgia Tech.

The first step in offering a customized course is gaining an understanding of the goals of the students for the discussions, learning essays, assignments and evaluation to suit the individual's educational needs. The orchestration tools used in such a setting encourage active involvement of students in taking control over their own learning. Hence, the students learn the process of creating their own knowledge, i.e. learning how to learn. We discuss these orchestration tools in the context of a graduate level course 'ME6102—Designing Open Engineering Systems' semester.

Students are asked to identify and prioritize their personal learning goals in Assignment 0, which is handed out during the first day of the class. These learning goals are centred on the general theme of the course and the manner in which the course is orchestrated. Examples of personal goals include 'learning how to design open systems', 'learning how to design for changing requirements', 'learning how to validate a design method', 'learning how to formulate design problems', 'learning how to design for the environment', etc. These goals are utilized by orchestrators to customize the lectures and to provide individualized feedback. Further, defining

their own goals at the start of the course makes the students proactive towards their own learning.

The students are introduced to the Observe-Reflect-Articulate paradigm of learning and are encouraged to represent their work using these steps. With an understanding of the manner in which learning takes place, the students are empowered with the ability to provide customization at their own level. It also brings out the process of individual learning and helps the orchestrators to understand the learning process of each student.

During the first lecture, the students are also given a Question for the Semester (Q4S). The answer to this question is due at the end of the semester and all the activities throughout the semester are targeted towards answering it. The Q4S for ME102 is as follows: we imagine a future in which geographically distributed engineers collaboratively develop, build and test solutions to design-manufacture problems encountered in the product realization process. In this context, we want you to provide a method to support the realization of mass customized industrial products for a global marketplace through distributed design and manufacture. For answering, the course is partitioned into three phases:

1. defining the world of 2020;
2. understanding the world of today and identifying gaps;
3. developing the design method for 2020.

The lectures and assignments are used to scaffold students' response. In the first phase, they are asked to identify the changes that will take place by 2020 and describe the environment in which they will be working. Depending on their interests and research field, they highlight different aspects such as collaboration, globalization, environmental considerations, outsourcing, etc. This provides significant opportunity for students to personalize the Q4S and identify specific aspects of the world of 2020 they want to focus on. In the second phase, the focus is on analysing design methods in use today and identify their shortcomings in addressing future needs. In the third phase, various approaches and methods for designing systems for 2020 are discussed from the standpoint of designing Open Engineering Systems.

The definition of Open Engineering Systems is: 'they are systems of industrial products, services and/or processes that are readily adaptable to changes in their environment which enable producers to remain competitive in a global marketplace through continuous improvement and indefinite growth of an existing technological base' [9]. Examples of approaches for designing Open Engineering Systems include modularity, robustness, product architectures, standardization, handling uncertainty in design, validation, distributed design, mass customization and strategic design.

Every week, the students are asked to write an essay on learning in which they get the opportunity to articulate how the content covered in the class

relates to their goals. The students are not provided with any fixed structure for learning essays. The essays enhance creativity and allow students to focus on aspects that are most important to them. Hence, learning essays provide an avenue for personalizing students' learning. Various authors [10–13] discuss the effectiveness of similar learning essays (journals) in design courses. These journals not only allow students to reflect on the material presented in the course but also provide valuable feedback to the instructors about the effectiveness of lectures. The essays can be used by the instructors to adapt the presentation of material to suit the students' learning needs.

Learning essays are complemented by various assignments that are heavily loaded towards answering the question for the semester. The students are provided broader assignments that can be customized by the students based on their individual interests. As opposed to learning essays, the assignments have a well-defined structure so that the students can follow the process of Observation, Reflection and Articulation. The orchestrators provide flexibility in terms of submission dates of assignments to allow the students to learn at their own pace. Collaboration with other students is a key ingredient in the course. The students are provided best practices from other students who are either in the class or have taken the course previously. These best practices encourage students to learn from their peers. Using best practices, the students are able to build on the work done by others, thereby adding value to the existing body of knowledge. The orchestrators provide personalized feedback to the students on learning essays and assignments. The feedback guides the students on their next steps. The students' submissions are not graded until the end of the semester. Hence, the students take greater risks without being constantly concerned about getting a good grade. Finally, at the end of the semester, the students create their own grading scheme based on their learning goals. Using this grading scheme, they evaluate their learning throughout the semester. By evaluating their own learning, the students identify their strengths and weaknesses and are able to identify the possible avenues for improvement. Ability of self-evaluation paves the way for lifelong learning.

In summary, mass customization of the course aids and empowers students both in their internalization of course content and their development of critical analysis, abstraction and synthesizing skills that in addition will help them become lifelong learners. We believe that this is a step towards in preparing our students for the flat world.

IT-ENABLED INSTRUCTION AND THE VIRTUAL CLASSROOM

Significant advances in IT facilitate real-time collaborations and have great potential for

changing the current learning environment. Key advantages of using the latest IT advances in distributed education include extension of the reach of education, adaptability to changing lifestyles and demanding schedules and availability of a richer diverse learning environment. Recently, various universities have realized the need for expanding their reach to a global scale. Their efforts range from offering web-based online courses [14] to developing IT enabled multi-university collaborations [15], also referred to as Virtual Universities [16].

Winer and co-authors [17] presented an overview of the Master of Science in Mechanical Engineering (MSME) degree offered through distance learning by the Woodruff School of Mechanical Engineering. The emphasis is on capitalizing the complete power and flexibility of the Internet rather than merely modifying standard lecturing methodology. The approach involves:

1. uploading the videos of lectures on a website;
2. utilizing graphics, animation, simulation and visualization techniques to reinforce the concepts discussed in the lectures;
3. bulletin boards for online discussions;
4. utilizing chat and teleconference capabilities for online office hours;
5. use of 'SmartBoard' technology to add production value to the lectures.

At Georgia Tech Savannah, our objective is to take this effort a step further. Georgia Tech Savannah incorporates novel distributed education tools such as electric whiteboards and advanced video teleconferencing systems into geographically distributed courses offered within the Georgia Tech Regional Engineering Program (GTREP). The purpose of GTREP is to provide increasing access to engineering education for southeastern Georgia students with the partnership of three institutions—Armstrong Atlantic State University, Savannah State University and Georgia Southern University. The established environments of distributed education classrooms and tele-collaboration studios at Georgia Tech Savannah make it possible to reach more students and enable collaboration with off-campus researchers in efficient ways.

Balancing the synchronous and asynchronous learning environment

A key challenge in distributed education is achieving a right balance between the synchronous and asynchronous aspects of communication to maximize individual learning. The traditional learning style, namely synchronous learning through face to face interaction between faculty and students, is still a dominating approach in today's higher education. Its weakness is distance and time constraints for instructors and students. Alternative methods are required. Advances in new technologies, such as 3D visualization, simulation and networking, provide new learning experiences. Asynchronous Learning Networks (ALN), that employ information technology, include self-study learning methods (i.e. computer-based learning, viewing tapes, reading, etc.) and asynchronous people-to-people interactions as shown in Fig. 3. Accordingly, ALN represents the idea that people can learn at different times and different locations; namely anywhere-anytime learning networks [8].

Although ALN clearly shows advantages for distant and local education in terms of learning time and learner's performance, it requires extensive preparation and planning for the development of class materials to make it as effective as the traditional learning environment [7, 8]. Thus, a combination of ALN and modest synchronous mechanisms can be considered an optimal solution to providing higher education through distance learning programmes to off-campus students.

Integration of IT-enabled instruction tools into geographically distributed course

Important advances in IT-enabled instruction tools, such as electric whiteboard, Tablet PC and video teleconferencing technologies, can facilitate real-time collaborations and have great potential to change the current learning environment. Georgia Tech Savannah incorporates these new technologies into geographically distributed courses. The students of the partner institutes attend classes through the distance-learning connections under the GTREP; namely, a teacher and students are physically distributed in multiple campuses. In a selected course, e.g. ECE2025: Introduction to Signal Processing, faculty members are exploring

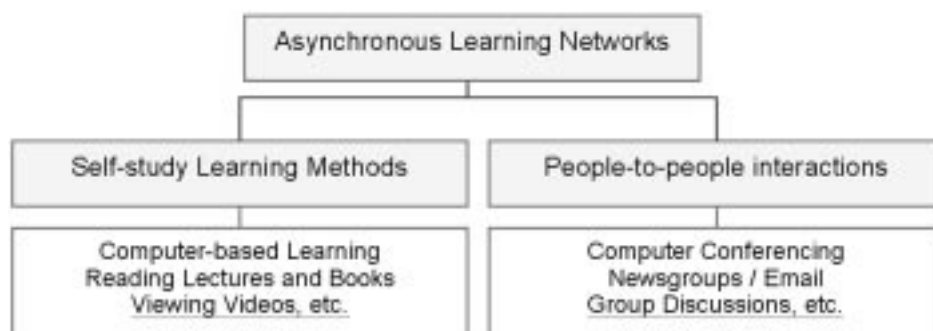


Fig. 3. Components of asynchronous learning networks (ALN).

the usefulness of the Tablet PC for various learning activities of the geographically dispersed groups including scientific visualization, data exploration and analysis, engineering design procedures and team projects. During the class, students work in groups for class projects/questions and demonstrate the efficacy of the Tablet PC to the applications of dynamic systems. This kind of problem-based learning is identified as one of the best pedagogical practices for improving learning of design concepts. The multi-campus student group will prepare and present their project work in class and orchestrate the ensuing class discussion via Tablet PC which provides the capability to write with a stylus. The main benefit of this technology is that it enables a balance between synchronous and asynchronous aspects of the learning environment. For instance, all students in the class can submit their feedbacks to the instructor through the Tablet PC and the instructor can display the best submissions to all for the benefit of all students. This allows better communication and greater attention from the students. This feature is particularly very useful in geographically distributed courses. In addition, a Tablet PC also helps self-study activities such as computer-based learning and reading lectures through the equipment, since it also provides the functionality of a traditional notebook computer.

GTS has identified the efficacy of the IT-enabled instruction tools to enhance the teaching and learning environment of undergraduate and graduate engineering classes in which a teacher and students are physically distributed to multi-campus. This test-bed effort can be a role model for geographically distributed courses which should be able to support real-time feedback and team project collaboration through IT-enabled instruction tools. The long-term goal of the current effort is to establish a virtual and collaborative learning environment that increases student motivation and success in education through advanced IT technologies. GTS currently pursues a new education programme that integrates engineering and business or education and prepares students for careers in IT-enabled engineering. It is expected that the identified results of the current GTS's IT-enabled learning environment will contribute to construct a teaching/learning role model for geographically dispersed courses.

INITIATIVES AT THE WOODRUFF SCHOOL OF MECHANICAL ENGINEERING IN SAVANNAH RELATED TO ENGINEERING EDUCATION IN THE FLAT WORLD

GTRP: a collaborative engineering program

As previously mentioned, the Georgia Tech Regional Engineering Programme (GTRP) is an academic collaboration between Georgia Tech and its three partner institutions—Armstrong Atlantic

State University (located in Savannah), Savannah State University and Georgia Southern University (located in Statesboro). During freshmen and sophomore years of the undergraduate program, students are enrolled through one of the three partner institutions. These universities offer all of the mathematics and science courses as well as some of the engineering courses required in the first two years of the Georgia Tech engineering curricula. Before their junior year, students apply for transfer admission to Georgia Tech and complete their degree programme as a Georgia Tech student. During their junior and senior years, students are taught by Georgia Tech Savannah faculty supplemented by distance learning connections. Non-engineering portions of the degree programme continue to be offered by the partner institutions during junior and senior years. Currently, GTRP offers undergraduate degree programmes in civil, computer, electrical and mechanical engineering. Students graduating from GTRP receive a Georgia Tech degree with the designation Regional Engineering Program.

A global product creation network

Recently, Georgia Tech Savannah, the Technical University of Eindhoven in the Netherlands and the Indian Institute of Technology, Kharagpur have developed a shared vision and decided to jointly realize a premier global network for product creation (PCN). The Product Creation Network is a joint enterprise between academia and industry with the purpose to educate Strategic Engineers for the near tomorrow, focusing on the development of innovative methodologies, processes and technologies. The mission is to create and nurture leaders and to pioneer knowledge in product creation to fuel sustainable economic growth through continuous innovation.

From a university perspective, this network seeks to further design science and educate design engineers who create high value added products and processes that efficiently and effectively accommodate:

- Dynamic global markets and associated customer requirements.
- Dynamic global business processes.
- Technological innovations.
- Collaborative, distributed, multicultural, international environment.

The academic institutions involved with the PCN are developing a joint degree programme and associated courses to create the transdiscipline of Industrial Engineering Design (see Fig. 4), which will be offered to their students in the US, Netherlands and India. Course features include design at the core of the engineering curriculum, course content anchored in research findings, competency-based evaluation and learning through doing. These courses will be taught cooperatively by all the parties involved. While most of the content will be delivered via distance learning,

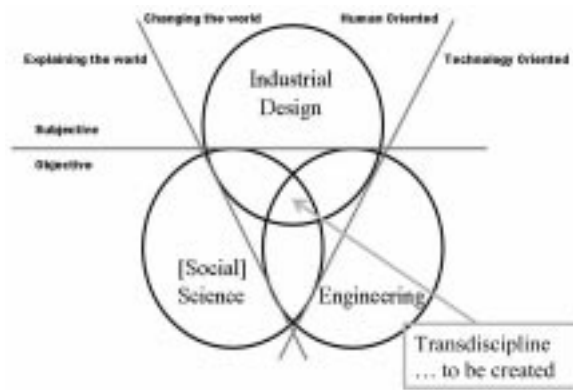


Fig. 4. Transdiscipline of Industrial Engineering Design to be created (courtesy Schouten, M.J.W., Industrial Design Programme, Technical University of Eindhoven).

the programme will also encompass elements that require students to spend some time abroad in order to get a better understanding of cultural and societal issues relevant to design.

As mentioned above, there are also industrial partners involved in the PCN. From their perspective, the product creation network seeks to further design science and educate design engineers who create high value-added products and processes that drive and sustain the economic viability of companies in an industrialized world thereby sustaining the economic and ecological well-being of the global community.

With regard to product development, the initial focus of the PCN will be the realization of products that embody ambient intelligence and the materials that are needed to make these products a reality. The Product Creation Network seeks to establish a particular value stream that allows its academic institutions and industrial partners to act in accordance to jointly reach a higher level of value creation (see Fig. 5).

Simply put, the product creation value stream could be described using a metaphor: 'the cowboy and the farmer can be friends'. First of all, universities (the cowboys) create wild ideas. Wild ideas are those that may fuel innovation, which

occurs at the boundary between existing knowledge and free thought. Creating wild ideas involves the development of disruptive technology and strategies, brain-storming and cross-functional communications across the PCN as well as an understanding of emerging markets and customer needs. Industrial companies (the farmers) are predominantly interested in ideas that most likely will be commercially successful. In other words, a vast number of wild ideas have to be filtered to keep only the good ideas. Commercialization occurs at the boundary between innovative ideas and tangible products. Consequently, industries are only interested in good ideas, which form a sweet spot in the area where innovation and commercialization intersect.

CLOSURE

In this paper, we shared our thoughts on how to strategically redesign engineering education in order to position the Woodruff School of Mechanical Engineering for what lies ahead in terms of meeting the challenges of a flat world, rather than waiting for time to pass and then trying to respond. A number of associated issues regarding the development of future engineering curricula and programmes, ways to adapt them to the flat world, the customization of engineering education, as well as the utilization of IT to enhance student learning in distributed educational settings are discussed.

We recognize that much remains to be done and that what needs to be done cannot be done by us alone. Accordingly, we invite you, our colleagues, to join us in identifying what needs to be done and how we can have fun in defining the emerging science-based discipline of design. Fun in providing an opportunity for highly motivated and talented people to learn how to achieve their dreams. Collaboratively, we can live up to what Joel A. Barker once said: 'Vision without action is merely a dream. Action without vision just passes the time. Vision with action can change the world'.

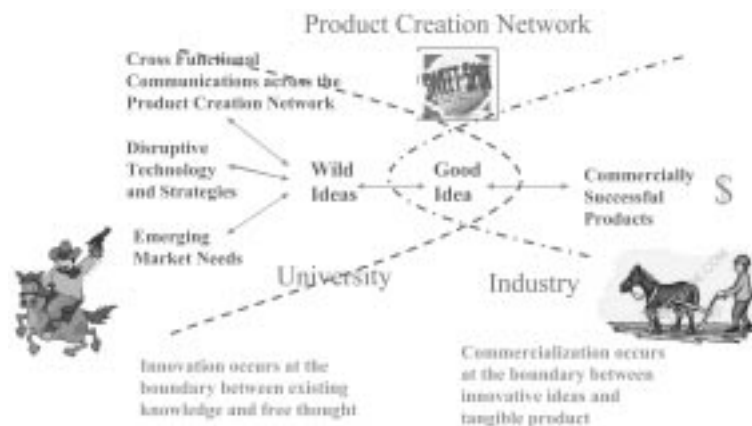


Fig. 5. Product creation value stream within the PCN.

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